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Investigation of electric vehicle grid support capability

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Abstract

Within the scope of the e-SolCar project, which aims to improve the urban gridstructures in view of the future challenges in photovoltaic generation and loadsfrom e-mobility, the fleet consisting of 41 battery electric vehicles (BEV) has beenput into operation. At the central campus of the BTU Cottbus, 15 of them are used as test objects. TheseBEV are supplied through 100 kW peak PV, stationary batteries (of 2000kWhinstalled capacity) or the main grid, depending on system situation. In the nearfuture, these electric cars will also be able to give the stored energy back to the grid(V2G). This ability will be applied in order to check the technical feasibility and thepotential contribution to grid stability, since electric cars will be used not only asloads but also as positive and negative control powers. After a fleet testing phase of almost one year, we were able toanalyze some acquired data. For instance, thecalculation of the real available capacity has been contrasted with the theoreticallyinstalled battery capacity. Furthermore, we took a closer look at particularities ofthe mobile storage system, such as experiences with charging electric vehicles (BatteryManagement System), handling high-voltage batteries, problems, advantages and disadvantages of the mobile storage system, recommendations andnecessary improvements. Finally, the results of the cooperation between electric car manufacturerGerman-E-Cars R&D and BTU researchers in the field of communicationbetween grid system and BEV as well as application of V2G are presented.

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1. Introduction

The project e-SolCar undertakes research in the field of integrated solutions forfuture smart grid scenarios,combining the competencies of three organizations.In the energy economy field,themain partner is the company Vattenfall Europe Generation AG.German E-Cars Research & Development GmbH is the partner specialized in the field ofelectric vehicles technology. The tasks of the Brandenburg University of Technology Cottbus-Senftenberg (BTU) include carrying outresearch anddevelopment activities in the areaof e-mobility, renewable energy and grid stability, and to act asthe scientific coordinator between the partners.

In order to investigate the impact of the increasing generation and supply of renewable energy sources, as well as of additional loads from e-mobility on low and middle voltage grids, a micro-grid system together with charging stations for electric vehicles was developed and erected. This micro-grid was built in a way that allows research activities to be carried out in stand-alone as well as grid-connected.

The micro grid in stand-alone system (without connection to the main grid system) consists of a solar power system with a P=116.6 kWp, a stationary battery with approximately 500 kWh usable energy (installed 2000 kWh), as well as a current-controlled heat and power unit withP= 27 kWel.

The charging park is composed of 16 charging stations near the micro grid at the BTU campus. These stations are already equipped with a CP-conductor of type-2 connector in order to extend the communication with the electric vehicles. This communication technology is the research priority of the e-SolCar project and is not in accordance with the currently recommended Smart Grid communication on the basis of the Home-Plug Green PHY technology. The charging stations supply the energy to the 15 battery electric vehicles (BEV) named CETOS, which were converted from Opel Corsas, and to abattery electric utility vehicle named PLANTOS (an electrically converted Mercedes Sprinter). The development and implementation of these BEV was carried out by the company German E-Cars GmbH.

The communication between charging stations and electric vehicles serves to optimize the loading processes of the local and stochastic available batteries of electric vehicles. The stored capacity of each BEV is about 21,4 kWh (CETOS) and 38,8 kWh (PLANTOS).

Currently, all charging stations and electric vehicles are equipped with communication technology, and the first bidirectional charging battery electric vehicle prototype is already in the field. The next step is to upgrade the other batteries with bidirectional charging (V2G). This way, the flexibility and practicality in investigating the use of e-mobility fleets for grid support such as control power (provision of positive and negative power depending on grid situation) will be enhanced.

Since July 2012, the most important electrical parameters (I, U, S, P, Q) are recorded every second by means of four-quadrant measuring instrument. In addition, the 16 BEV users are instructed to keep the driver’s logbooks in order to record driving information, such as start and final mileage, State of Charge (SoC) at the beginning of the charging process, departure and arrival time, etc.

2. Methods and Results

2.1. Energy economics and users’ analysis

In order to gain improved knowledge concerning commuting and driving behavior, theemployees of the BTU Cottbus-Senftenberg were invited to apply for testing and using the electric cars. Before selecting the drivers, we divided the volunteers into five different distance ranges (2-5km, 5-10km, 10-20km, 20-40km and 40-60km), so that a wide range of commuters with different driving habits would be available. In total, 60BTU employeestested 15 electric vehicles in their daily routines for two years in four phases, with each phase lasting six months. After the first two test phases,relevant data were collected and analysed. During this period, a total 4,677 official and 1,384 private journeys were undertaken with the maximum travelling distance of 120 km per journey. It should be noted that the use of electric vehicles differsaccording to each particular distance range. The drivers with longer distances between their home and workplace use the car for private purposes less often. In the first two test periods, the 15 cars drove a total mileage of about 111,000 km and consumedapproximately 27.75 MWh. Due to the different distancesbetween home and workplace, the mileages covered by the test drivers vary greatly. The shortest covered distance was 1,264 km in the smallest distance range (2-5 km), while the longest mileage was 16,148 km in the range of 40-60km. The average energy consumption of the electric vehicles during this testing period was about 25 kWh per 100 km, which is equivalent to € 6.25 based on the current energy price of 0.25 €/kWh. Since the drivers register the stage of the charge at the start and end of each journey, it is possible to develop a simple charging curve for the fleet. By means of our vehicle batteries, it is possible to smooth the power generation of our photovoltaic facility. During a cloudless sunny summer, our PV (installed power 116.6 kW peak) could generate a total energy of 672 kWh. Figure 1 shows a charging curve of a single random day when all the electric vehicles were plugged to the charging stations.

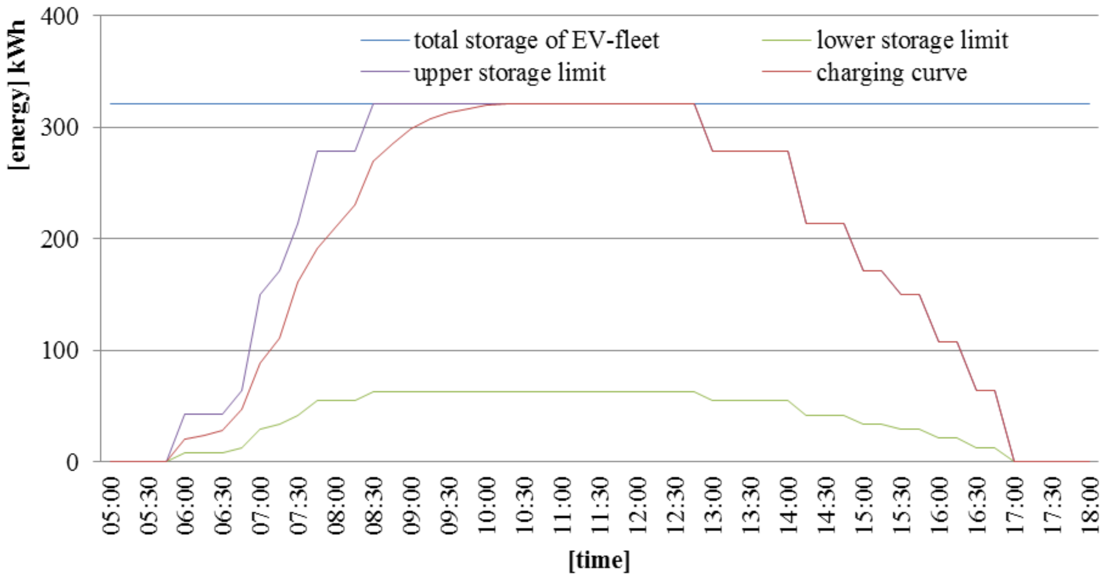

Fig. 1:EV-fleet storage capability.

The straight blue line shows the upper storage limit of 321 kWh if all 15 charging stations were on duty and each car had a capacity of 21.4 kWh. The green line represents, according to the manufacturer, the lower storage limit that should not be reduced in order to prevent the rapid aging of the vehicle batteries. At this limit, the vehicles must be discharged to buffer the fluctuating photovoltaic or wind power feeds. The purple line shows the available storage in the positive direction, while the red line explains the charging status of the vehicle pool. In this example, the directional loading of the electric vehicle is shown where the vehicles were loaded to their full capacity of 21.4 kWh. The full load was achieved for the 15 vehicles at around 10:15 PM. When controlled, load-oriented and bi-directional charging is carried out, the charging curve (red) is used to adjust to the requirements of the power system grid, i.e., during periods of high and fluctuating renewable generation vehicle batteries can provide excess power or control energy.

2.2. Data regardingmobile electric vehicle storage

The increasing use of renewable energy sources for electricity leads to a growing need for storage solutions. Since battery memory in electric vehicles is likely to become increasingly available over the next few years and the energy supply isoftenunable to meet the demand, battery memory could have an important back-up function in the future. During their idle hours, electric vehicles are particularly suitable for the load management in the power supply network. They can be storeenergy surpluses from renewable energy sources and feed the electricity back into the network, depending on particular requirements. In purely arithmetical terms, the electrical power per vehicle is 22 kW to store energy. There are high requirements on the necessary complex control procedures, high initial costs for the battery storage, the need for extensive grid expansion and requirements regarding the users' driving habits. With suitable logistics support, the vehicle storage can be effectively used,responding to consumers' needs and causing less transport losses. However, losses may still occur resulting from the transformation processes (DC/AC). This proportion can be greatly reduced with modern loader topologies.

Unfortunately, the vehicle storage has specific limit values, such as the small number of recharging cycles, which have a significant influence on the battery durability. This aspectshould be taken into consideration in the corresponding payment models. Currently, the most used energy storage unitsare lithium ion batteries. They have an excellent power and energy density and a high cycle resistance compared with traditional storage devices.In light of technological progress, the lithium ion technology has the highest development potential. Currently, this has a negative effect on the purchase price.

2.3. Communication between electric vehicle, charging infrastructure and vehicle-to-grid

The communicative connection between electric vehicles and charging stations is provided by a charging cable with connected type 2 plugs. To this end, the CPuses a PWM duty cycle of 5%, such as defined in the European Standard EN 61851.[1]

Fig. 2:Oscillographic curve of the communication signal (PWM duty cycle of 5%)

Contrary to the recommendation of the draft standard, ISO/IEC 15118 is only used in the negative voltage range of the PWM signal (-12V) for transmission messages. [2]

The charge controller of the charge station can only be used in the positive voltage range. This way, the load cannotbe interrupted if a tolerance of 5% of the PWM duty cycle is exceeded.

Consequently, both sides may exchange any information. A high-level control centre collects and processes information and re-transmits control signals for the battery charging in the electric vehicle, giving the user flexibility to organize his timetables. In addition to this control of the gridstructure, the interests of the vehicle user will be included. With an HMI-Input, the vehicle user can determine the restrictions for a single charge-discharge cycle, to which a high-level controlmust be subordinate. This includes information about the presumed departure time and the amount of reserve energy in the vehicle battery, which can be stored or charged anytime.

In addition, the charging parameters and information about the charging status in particular will be exchanged.The following figure depicts the exchanged data during the bidirectional charging. The visualization helps to identify and understand the parameters that define the charging process. Data regarding the condition, energy level, charging and time performance are conveyed, providing the system with information about the battery and the charge and discharge process. Furthermore, the user's demands entered into the vehicle's HMI are taken into consideration.

Fig.3:Visualization of the exchanged data (via CAN-Bus)

The aim of vehicle-to-grid (V2G) is to automatically control each charging process and, in their aggregation, to create overall timetables taking special account of user acceptance. These timetables are effective in dependence of exogenous factors of the electric grid andare beneficial to the system, since they contribute to grid stability.

2.4. Vehicle-to-Grid (V2G)

For storage and recovery of electric energy from the grid in the electric vehicle, a bidirectional charging device will be used. It is located in the vehicle not only to provide the necessary electric energy for a lithium ion battery, but also as an energy recovery system, especially under high network loads. This device enables a smooth operation for base load and medium load plants, particularly in the provision of peak load current.

The bidirectional charger is directly connected with the communication device between charging station and electric vehicle (CAN-Bus). It makes the requested quantity of voltage, current and power available. Two levels supported by microcontrollerallow for a three-phase connection to the electric grid up to a power of 22 kW.

The use of modern semi-conductors using a high switching frequency and the connection to a water-cooled systemmake a high packaging density with high efficiency possible.

The bidirectional charger can be used in all electric vehicles employed in the project because it features a high DC voltage range.Due to the high voltage and current during the operation, the charger includes a series of securitymechanisms, e.g. the monitoring of all current performance parameters and temperatures. Furthermore, it takes all practicable steps to identify and avoid possible malfunctions and ensure staff safety. One example is a strict separation between vehicle 12 V on-board supply and the high-voltage vehicle power electrics and the electrical isolation between control and power section.

Figure 4 shows the progression of complex power during a bidirectional charging process, as in opposition to the progression of the adjacent voltage in the phase L1.

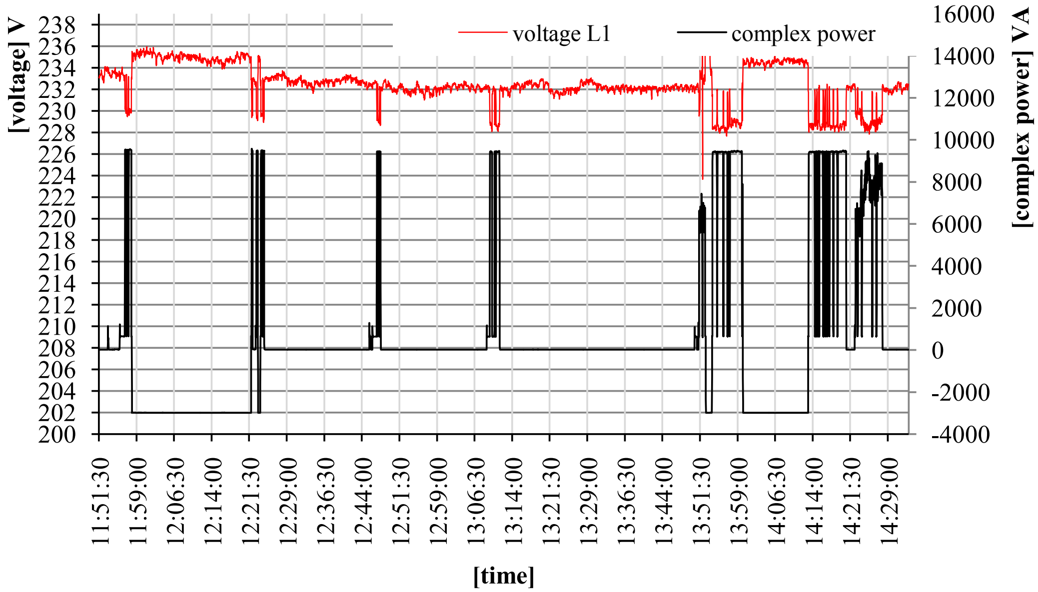

Fig.1:Trend of voltage and complex power at bidirectional load

In this energy recovery attempt with the electric car, 1804.28 Wh were discharged and 3511.99 Wh were charged. This result indicates that the charge and discharge process can influence the voltage of each particular phase. During the charging cycle, positive complex power reduces the voltage; during the discharging cycle, with negative complex power, the voltage tends to increase.

3. Conclusion

Research and developmentactivities in the project e-SolCar contribute to a harmonious coexistence of e-mobility and renewable energy generation, as well as to the maintenance of grid system stability. Subjects that are difficult to manage due to their specific and opposing characteristics demand a new innovative approach. The most important key to meet this challenge is a close, intensive cooperation between professionals from different fields, e.g. electrical engineering, automotive engineering, power generation, etc.

The analysis shows that the charging and discharging of the electric car battery works in practice as well as in theory. The next task within the project is to equip the further 15 electric cars with the V2G technology. The aim is to find out if the aggregation of individual car storage batteries is able to provide additional value for a microgrid or the public power supply. Thanks to this way of working, e-SolCarhas established itself as a successful research project where significant milestones have been achieved, such as thecommunication between grid system and BEVand the application of V2G.

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